PROCEEDINGS OF SCIENCE

Thermal flares from collapsed accretion disks?

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I discuss the possibility of thermal flares resulting from the collapse of the accretion disk in X-ray binaries. I calculate the resulting spectra and lightcurves from blackbody radiation and thermal bremsstrahlung assuming a simple, spherical and homogeneous, wind-like outflow of the collapsed disk matter. The results suggest that if a significant part of the inner accretion disk matter is expelled as a windlike outflow, the radiation from the expanding plasma could indeed be seen as a very fast flare in some sources. In particular, the model could help in understanding the soft-X-ray spikes during the X-ray dip phase and preceding the radio flares in GRS 1915+105.

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1. Background

Relativistic blobs in jets from both active galactic nuclei (AGN) and X-ray binaries (XRB) are thought to originate from the accretion disk around the central compact object. The collapse of the inner part of the disk is assumed to load the jets with hot plasma, which is then accelerated to high velocities and ejected from the system in polar jets. The disappearence of the innermost and the hottest parts of the accretion disk is the likely cause for the observed decrease of the X-ray flux, and the subsequent brightening of the jet and appearance of new blobs provide strong support for this disk–jet connection in AGNs as well as microquasars (see, *e.g.*, [1] and [2] and references therein). Furthermore, observations of the microquasar GRS 1915+105 have identified a very short X-ray spike – lasting only a few dozen seconds and occuring at the end of many X-ray dips – as the trigger of the the ejection [3, 4], but the mechanism behind the spike is still unclear.

We have previously studied the possibility that in AGNs a part of the collapsing accretion disk material is expelled from the centre as a windlike outflow (while a part still gets injected into the jet and later become visible as a moving knot), and whether or not the resulting radiation could be detected in the current data [5, 6]. In AGNs the scenario leads to a very short orphan optical flare starging at the collapse of the disk, followed later by a multifrequency flare when the jet-injected part of the collapsed matter reaches the base of the visible jet months or even years later. Unfortunately, the combination of infrequency and unpredictability of these collapses (expected to happen at a rate of once every 0.5–3 years), the underlying strong variability from the jet, and the short duration of the flares (only lasting for a week or so) make them extremely difficult either to observe or to rule out.

Here I have tested the idea tha these thermal flares, if they exist, could be move easily observed in microquasars where the accretion/ejection cycle work on timescales in hours instead of decades or centuries as it the case with AGNs. For the first test I have applied the model of [5] to the microquasar GRS 1915+105 simply by scaling down the physical parameters. Detailed model for XRBs needs to be developed later if the results and the further analysis support the feasibility of this approach.

2. The Model

In order to test the feasibility of the thermal flare hypothesis, I use a simple "spherical cow" approach[5], where a uniform and isotropic sphere of thermal plasma expands and radiates via blackbody and bremsstrahlung mechanisms. In the beginning, following the idea of a collapsed accretion disk, the plasma has the temperature and the mass comparable to the inner accretion disk parameters, and it is concentrated spherically within the radius of a few gravitational radii (excluding the volume within the event horizon). At $t = 0$ the sphere starts to expand at a constant speed while the electron-positron plasma begins to lose energy due to radiative losses and adiabatic expansion. Many XRB-specific components and effects (radiation and wind from the companion star, inverse Compton scattering off coronal and disk electrons, *etc.*) have been omitted at this first stage.

Also modelling the disk-jet connection is beyond the scope of the present study. If, however, the thermal flare is indeed connected to jet injection, one would expect systematic delays between

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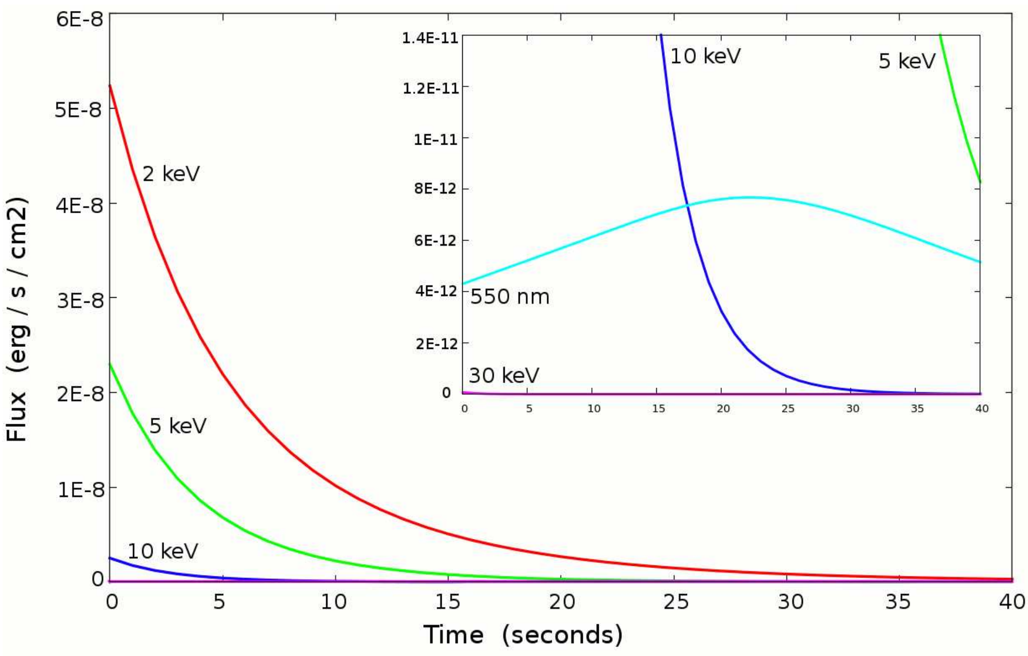

Figure 1: Simulated lightcurves for a GRS 1915+105 flare (expansion begins at $t = 0$). The optical 550 nm and the hard X-ray 30 keV lightcurves are visible only in the insert with zoomed-in y-axis. See text for details.

the flare in the centre and the appearance of a new jet feature. Interestingly, this delay may have been observed, *e.g.*, in another microquasar, Cygnus X-3, where many of the first flares of prominent flare couples are show flatter spectra, consistent with the presumed thermal origin, while the latter ones are best fit by synchrotron emission from relativistic electrons when the jet becomes visible, and where the ejected blob in the jet is estimated to have left the centre during the first flare (Miller-Jones et al., in preparation).

It is also important to point out that the current model starts when the collapsed plasma begins to expand. Modelling the whole flare is work in preparation, and the results shown in the next section only account for the supposed expansion of the plasma. Furthermore, to avoid confusion, I emphasise that this central thermal plasma modelled in this work and assumed to be responsible for the short X-ray spike is not to be confused with the matter injected into the jet and well modelled with the van-der-Laan-type models of expanding, synchrotron-radiating blobs moving in the jet (*e.g.*, [4] and references therein).

3. Results and discussion

Fig. 1 shows an example of the resulting flux curves computed for GRS 1915+105, assuming a mass of $10^{-12} M_\odot$ ($\sim 2 \times 10^{22}$ g) initially within the initial radius of 3 r_g in the temperature of 2×10^7 K ($kT \approx 1.7$ keV), starting to expand at the speed of 500 km/s. In the X-ray energies the plasma is optically thick from the beginning, and the cooling leads to a decaying flux, initially reaching the levels of the order of 10^{-8} erg cm^{-2} s^{-1} in the soft X-rays ($\sim$2–5 kev). At a given

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frequency the flare duration mostly depends on the expansion speed, but with parameters of this order of magnitude it is only a few dozen seconds. Also the optical flare, peaking at 14 mJy after ~ 20 seconds, is rather strong, but lasts only for a minute or so. As was the case with AGNs, also here the radio signatures are negligible.

It is interesting to note that the resulting fluxes and the decay times in this simple example are rather similar to the observed decay-phase of the X-ray spikes. For example, Vadawale et al. [9] reported strong soft-X-ray spikes lasting for a few dozen seconds and reaching a level of approximately 5×10^{-8} erg cm^{-2} s^{-1} above the background. Furthermore, recently Prat et al. (ref. [4] and elsewhere in this volume) confirmed the occurrance of these spikes at the end of the X-ray dips and their connection to the ejection of new relativistic jet component; they speculated that the spikes are caused by slower accretion of new matter in the centre, followed by a sudden fall due to ejection of the matter in the form of expanding blobs.

Unfortunately for detailed testing, the least-well-known input parameter, the mass of the ejected plasma, affects the results the most. On one hand, for GRS 1915+105 there are estimates of mass as high as $10^{-10} M_{\odot}$ ejected during the largest flares and an order or magnitude less in smaller ones [7], while on the other hand the estimates or the minimum ejected mass are of the order of $10^{-15} M_{\odot}$ [8, 2]. The Fig. 2 shows the simulated peak fluxes for different masses as well as the two mass estimates from the literature (the shaded areas). With the given parameters and assumptions, the mass range best fitting the typical observed soft-X-ray flare levels of $(5\text{–}10) \times 10^{-8}$ erg cm^{-2} s^{-1} is around $10^{-12} M_{\odot}$ for the 2 keV flux. This is three orders of magnitude higher than the lowest mass estimates, but also one or two orders of magnitude lower than the highest.

4. Summary

I have studied the thermal emission from expanding plasma with the initial parameters similar to those in the inner accretion disk. The toy-model results show interesting resemblance to the second-timescale decay of the soft X-ray spikes observed consistently at the end of X-ray dips in GRS 1915+105.

The results suggest that if a significant part of the inner accretion disk matter is expelled as a windlike outflow, the radiation from the expanding plasma could be seen as a soft-X-ray flare in some sources. Thus, the model could help in explaining the soft-X-ray spikes related to the X-ray dips during the ejection events.

The present model does, however, still lack many components known or believed to be present in XRBs, and makes many overly-simplifying assumptions and more development is needed before any serious comparisons to observations can be made. Still, it is intriguing that the time- and flux scales following even this simple spherical-cow calculation are so close to the observed ones – this was the case also with the AGNs studied, hinting that if these flares indeed exists and if they both can be modelled with such a simple model, this would mean great similarity in the accretion/ejection processes and the disk/jet connection in both sources, separated by over 8–10 orders of magnitude in size. Also the possibility that a significant fraction of the collapsing matter gets ejected from the system as a windlike outflow and does not contribute to the jet brightness would affect the accretion-power estimates based on the observed jet power.

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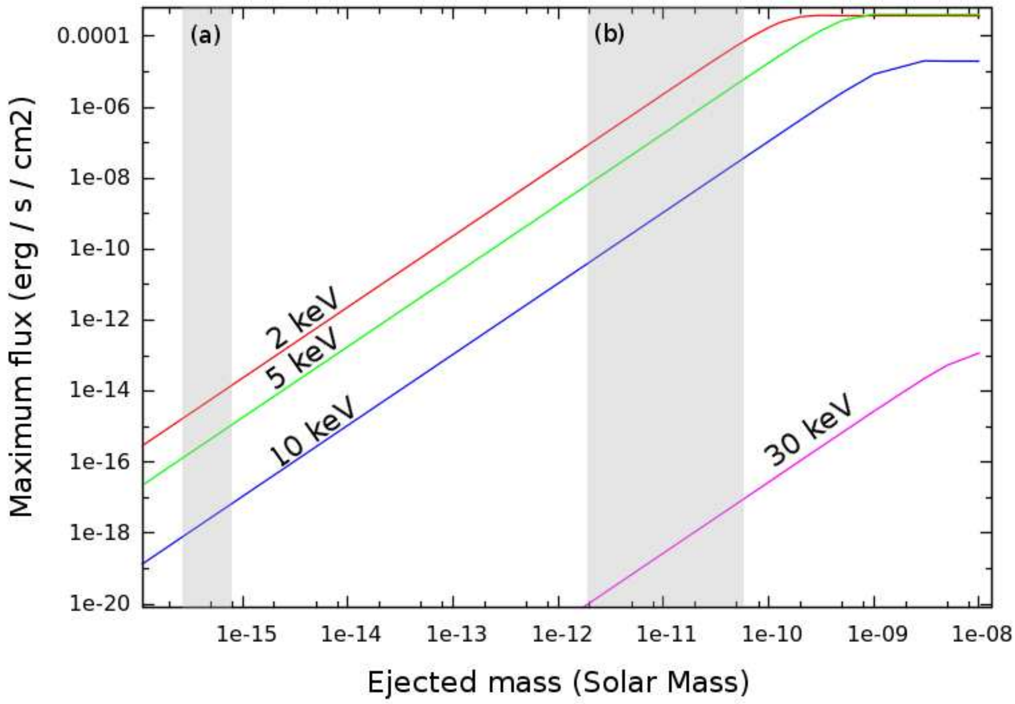

Figure 2: Peak X-ray flare fluxes for GRS 1915+105 as functions of the initial mass. The shaded areas show two different estimates for the collapsed mass during an X-ray dip (a) [8, 2], and for the total mass in the largest superluminal ejecta [7].

To conclude, similarly to the case of AGNs, also in the tested XRBs the thermal flare following a collapsing accretion disk could be directly observable and may even be observed repeatedly in the form of the soft X-ray spike. If the flare is indeed a real phenomenon, it could explain some observations as well as help to improve the existing models. However, more work is needed before more extensive and quantitative testing.

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